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ORIGINAL PAPER

Rethinking investment planning and optimizing net zero emission buildings

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Abstract Increased awareness of climate change has precipitated more stringent mitigation targets. Public sector institutions in Canada are committed to becoming carbon neutral to attain a leadership position in climate change mitigation-related initiatives. Recent statistics reveal that buildings account for the majority of the corporate carbon footprint of public sector institutions. Hence, there is an increasing interest towards developing net zero energy and net zero emission buildings to comply with climate action targets. With limited financial resources, public sector institutions must optimize investments into building energy retrofits by considering lifecycle cost (LCC), overall energy performance, and related greenhouse gas (GHG) emission. The aim of this paper is to develop an investment planning approach for net zero emission buildings (NZEB). First, an investment planning approach for NZEB is proposed. A typical recreational centre building in British Columbia, Canada, was used as the archetype to demonstrate the concept. Second, innovative and proven building energy retrofits were analysed using energy simulation software to assess the impact on energy consumption reduction, GHG emissions, and LCC. Third, impacts of geographical location, tariff regimes, and grid emission factors on energy retrofits were studied by locating the same building in other provinces of Canada. This study revealed that net zero energy investment has a strong correlation to the grid emission factor. The proposed approach in this paper will assist building managers and owners in retrofitting and budget planning.

Keywords Climate change · Net zero emission buildings · Energy retrofits · Decision-making · Investment planning

Introduction

One of the primary outcomes of the United Nations Paris Agreement in 2016 was a commitment to limit global temperature increase to 1.5 degrees Celsius above the pre-industrial levels (United Nations Framework Convention on Climate Change 2016). This target requires strengthening mitigation plans more than ever before. Reducing GHG emissions and the environmental footprint have been priorities of the Federal Sustainable Development Strategy (FSDS) of Canada from 2013 to 2016 (Environment Canada 2013). Canada is committed to the Copenhagen Accord and has targeted an ambitious 17% GHG emission reduction by 2020 (612 Mt CO_2 eq[1]) from the 2005 GHG emission level (738 Mt CO2 eq) (Canada's Action on Climate Change 2013). In 2012, GHG emissions in Canada reached 699 Mt CO_2 eq, which is a 5.2% decrease from 2005 levels. GHG emissions in British Columbia (BC) should be reduced 33% by 2020 and 80% by 2050 from 2007 levels (Ministry of Environment BC 2007). In 2012, BC reduced its GHG emissions by 4.4% from 2007 levels (Ministry of Environment BC 2012). Therefore, Canada has to pursue more aggressive strategies to achieve the

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[1] Mega tonnes of carbon dioxide equivalent.

Copenhagen Accord target by 2020 (Environment Canada). In order to support the ongoing climate action agenda, a majority of public sector organizations of BC signed the BC climate action charter and committed to becoming carbon neutral by 2012 (Government of British Columbia 2013). In the quest to become carbon neutral, municipal governments are compelled to implement programs and policies that contribute to a reduced carbon footprint of both corporate and community actions. Improving the energy efficiency of buildings is one of the most viable ways to achieve institutional climate action targets, since buildings emit approximately one third of the GHG emissions in Canada (Frappé-Sénéclauze and Kniewasser 2015).

Building industry initiatives to mitigate climate impact include net zero energy buildings, net zero emission buildings, net zero source energy buildings, and net zero cost buildings (Torcellini et al. 2006). These building types adopt energy efficiency features to reduce energy demand and supply the remaining demand via renewable energy sources (Steven Winter Associates Inc. 2014). Net zero emission buildings (NZEB) use emission-free energy and supply the energy demand through on-site renewable energy generation (US Department of Energy 2015). Advantages of NZEBs include minimized environmental footprint, minimized operation and maintenance costs, system reliability, and energy security (US Department of Energy 2015). The NZEB was identified as a key route to ambitious energy efficiency targets in BC (Frappé-Sénéclauze and Kniewasser 2015).

Energy retrofitting is the most preferred building GHG emission mitigation strategy (Estes 2011). Building energy retrofits aim to reduce GHG emissions, improve energy performance, and reduce fuel consumption while maintaining comfort levels (Picco et al. 2014) (Yu and Chow 2007). Common barriers for building retrofit projects include lack of funding, lack of interoperability, and unstructured decision-making (Woo and Menassa 2014). Despite a large number of policy instruments aimed at improving building energy efficiency, the pace of innovation is deemed inadequate (Altwies and Nemet 2013). Altwies and Nemet determined that this is the result of insufficient information, disjointed decision-making, principal agent problems, and lack of learning from similar projects (Altwies and Nemet 2013).

The feasibility of an energy retrofit depends on a number of factors, such as building characteristics and location (Liu et al. 2010; Kircher et al. 2010; Huang et al. 2013). The whole building energy system should be analysed to determine feasible energy retrofits (Zhao et al. 2009). This method should be capable of detecting abnormalities in building energy efficiency and to improve performance of the building (Escrivá-Escrivá et al. 2012). Budget limitations require innovative decision-making methods to obtain the best value for allocated funds. In building retrofitting, it is important to identify the retrofit that achieves the best reduction in energy consumption, GHG emissions, and operational cost (Wang et al. 2014).

Despite the availability of a large number of energy retrofits, analysing and identifying the most suitable retrofit remains a challenge (Asadi et al. 2014). Decision-making associated with energy efficiency investments is not straightforward (Hertzsch et al. 2012). Various appraisal methods have been used for evaluating building energy retrofits (Martinaitis et al. 2007). Though energy simulation software can estimate the impacts of an energy retrofit, the use of simulation software is limited to trained professionals (Chidiac et al. 2011). Building energy consumption, GHG emissions, and lifecycle costs (LCC) have complex interactions when identifying the optimal investment limit for retrofits. Energy, environment, economy, and timing of retrofits are the main decision criteria in building management. Since various retrofits are available for GHG emission, operational cost reduction is important when determining the optimal trade-off (Chiang et al. 2014). Reliable analysis of interactions between building condition, environment, and annual energy consumption is cumbersome (Peng et al. 2014). Optimization of building energy retrofits considering multiple factors has been overlooked by the building industry (Rysanek and Choudhary 2013). Hence, the retrofit planning process should be improved to obtain the best value for investment.

This paper presents a detailed investigation of energy retrofit planning based on regional characteristics and extends the concept to NZEB. First, a comprehensive investment planning method was proposed for NZEB. Second, the proposed approach was applied for an aquatic centre building operating in British Columbia, Canada. Innovative and proven building retrofits were identified and optimized to identify the best retrofit alternative considering energy consumption, GHG emission, and investment. Third, the impacts of varying climates and tariff schemes on the optimal retrofit were analysed for various provinces in Canada to determine the optimal net zero emission investments (NZEI). This study informs building managers in determining the investment required to achieve superior GHG emission reduction targets by incorporating regional climate and tariffs.

Literature review

Decision-making based on capital cost can be a significant drawback in infrastructure management, as it ignores the operating costs of assets, which can be substantial across the life of the constructed facility (iceberg effect)

(Wübbenhorst 1986; Bull 1993). Hence, lifecycle cost has become popular recently as a basis for making engineering-related decisions. More recent literature reveals that an integrated decision-making approach has been adopted in infrastructure-related decision-making. There are many innovative triple bottom line-based decision-making methods that assist infrastructure planning and management by incorporating social, environmental, and economic priorities into the evaluation. Innovative triple bottom line-based infrastructure management decision-making methods include water–energy nexus (Assaf et al. 2002; Hossaini et al. 2014); water–energy–GHG nexus (Nair et al. 2014); and eco-efficiency analysis (Seiler-Hausmann 2004) (United States Environmental Protection Agency (USEPA) 2014).

Identifying the optimal retrofit level for buildings has been a popular research topic in recent years (Leal et al. 2014; Ferrara et al. 2014). Ibn-Mohammed et al. (2014) have developed an approach to evaluating and identifying economically efficient building retrofit options that achieve the highest operational and embodied GHG reductions. Ashrafian et al. (2016) proposed a framework that helps identify energy retrofits from cost and energy savings. Chidiac et al. (2011) proposed a regression approach to estimating the impact of building energy retrofits. Leal et al. (2014) identified that medium efficiency is the best retrofit level from an economic perspective. McArthur and Jofeh (2015) suggested an approach that identifies strategic investments for building retrofits in a building portfolio. Jafari and Valentin (2015) developed an approach that identified the optimal retrofit level for a residential building based on energy consumption savings. Findings of this study were based on a single case study and required additional case studies to improve the validity of the findings.

Simulation-based optimization methods have been developed to identify a cost-optimal energy efficiency retrofit configuration (Ferrara et al. 2014). Asadi et al. (2012) used a TRNSYS, Genopt, and MATLAB-based multi-objective optimization model to select retrofit strategies. Asadi et al. (2014) proposed a genetic algorithm and artificial neural network-based model for assessing energy retrofits. A similar approach was used by Magnier and Haghighat (2010) to optimize the design of a building. Wang et al. (2014) proposed an optimization model for building retrofitting that maximizes energy savings and operational cost savings. Ferrara et al. (2014) tried a cost-optimal configuration of near net zero energy buildings. Malatji et al. (2013) proposed a multi-objective optimization model for building retrofits by optimizing energy savings and payback period. Shao et al. (2014) used a multi-objective optimization (MOO) model and stakeholder requirement analysis-based framework for decision-making for selecting building energy retrofits. Zhivov et al. (2013) proposed an energy optimization method for operating army buildings.

Net zero emission buildings (NZEB)

Similar to net zero energy buildings, NZEB is a new concept. Improving energy efficiency is the priority in achieving net zero energy/emission status. The remaining energy demand should be met by renewable energy sources that are economical, readily available, and replicable (Steven Winter Associates Inc. 2014). For NZEB, supply may be from on-site or off-site renewable energy sources (Torcellini et al. 2006). A building that is situated in an area with a clean electricity grid (e.g. hydro, nuclear) can achieve net zero emission status with lesser configurations than a similar building powered with electricity generated by a coal powered plant (Torcellini et al. 2006). Hence, the regional grid emission factor is important in NZEB (Torcellini et al. 2006). Because grid energy sources vary extensively across Canada, energy prices and carbon footprints of the grid vary extensively between regions. "Appendix" lists rates and GHG emission conversion factors for electricity and natural gas for Canadian Provinces.

Building retrofits are vital for achieving NZEB and they encompass efficiency improvements and renewable energy generation. Building energy retrofits are classified into three categories: minor, major, and deep retrofits, as discussed below (Natural Resources Canada 2014).

Minor retrofits Minor retrofits are low-cost, easy to implement modifications to a building that offer good value for the money and effort (low hanging fruit), e.g. air sealing of the building, upgrading lighting systems. These modifications can create considerable differences in the building's energy consumption (Natural Resources Canada 2014).

Major retrofits Major building retrofits are holistic modifications to buildings that can be installed with minimal disturbance to the building users. Several examples of major retrofits include replacing building fenestration items, upgrading the HVAC system, and installing automated controls (Natural Resources Canada 2014).

Deep retrofits Deep retrofits are expensive overhauls of the building envelope and HVAC system. Examples include roof replacements, installing ground source heat pumps, and rearranging window locations. Even though these options are highly disruptive to building occupants, they have the potential to result in high energy savings

(~60%). It is beneficial to combine deep retrofits with large-scale renovation projects (Natural Resources Canada 2014).

This study evaluates the impacts of energy retrofits on an aquatic centre building. Specific features of public aquatic centre buildings are explained below.

Public aquatic centre buildings

Published literature has largely overlooked performance assessments of public aquatic centre buildings. Only a handful of studies related to this subject area were found during the literature search. Howat and Crilley (2007) developed a performance assessment model for aquatic centres integrating customer service quality, satisfaction, and operational performance. Another study by Howat et al. (2008) examined the relationships among service quality, overall satisfaction, and customer loyalty for Australian aquatic buildings. This study revealed that the main factors influencing overall satisfaction are relaxation, staffing, and facility presentation. Priyadarsini (2014) studied energy performance of aquatic centre buildings in Victoria and revealed that annual energy use intensity in aquatic centres ranges from 632 to 2247 kWh/m^2. Sharma et al. (2008) mentioned that customer expectations, legislative requirements, and the community are important criteria for assessing the level of service for an infrastructure asset. Multipurpose public aquatic facilities can be financially viable sources of earning and can attract greater public participation. Public aquatic centre buildings consist of multiple areas such as swimming pools, gymnasiums, sports halls, cafeterias, administrative blocks (Trianti-Stourna et al. 1998); the floor area of an aquatic centre building ranges from 4883 to 7825 m^2 to accommodate these various functions.

Energy consumption within public aquatic centre buildings is quite different than regular commercial and institutional buildings. Figure 1 shows annual energy consumption within a typical public aquatic centre building (Trianti-Stourna et al. 1998).

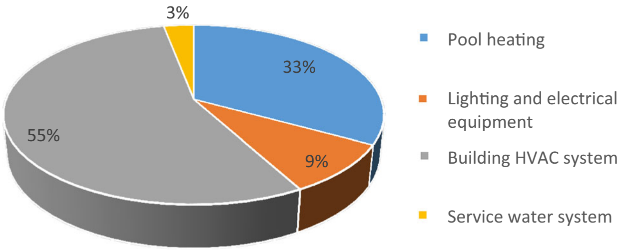

Fig. 1 Annual energy consumption in public aquatic centre buildings

Methodology

A sequential process was adopted to identify optimal investment and planning for building energy retrofits (Fig. 2). This generic framework could be adopted for different building types.

Case study

A sample aquatic centre building operating in South Okanagan, BC Canada, was used for demonstration purposes. As-built drawings were used to develop a 3D model of the building. The identified system was modelled using Design Builder V4 software environment. Building details collected from as-built drawings and expert input are presented in Table 1.

Figure 3 depicts the schematic view of the Design Builder model used in this study. The model was validated using annual energy consumption data (Shown in Fig. 4). Annual monitored energy values were compared with estimated values from the energy model.

Energy retrofits for aquatic centre buildings

Published literature was used to identify energy retrofits for aquatic centre buildings (Table 2). These retrofits have been successfully used in various aquatic centre buildings in Canada. Identified energy retrofits were simulated in the Design Builder energy building simulation software. Simulation results are presented in "Appendix".

Ranking energy retrofits

The objective of energy retrofits is to decrease annual cost savings, decrease energy consumption, and decrease GHG emissions. Hence, retrofit alternatives were ranked according to the 3Es (energy, economy, and environment). Energy simulation and LCC analysis results for each retrofit were normalized to obtain a score for each parameter. Scores for the 3Es were combined using the weighted sum method to obtain a final score. Equal weighting was considered for the 3Es. The final score was used to rank the energy retrofits considered.

Investment planning for NZEB

Results of energy simulations for retrofit alternatives were used to determine energy cost reduction, GHG emission reduction, and LCC for various retrofit investments. Maintenance cost was assumed to be included in the installation cost contract. Equations (1–4) were used to calculate the aforementioned values.

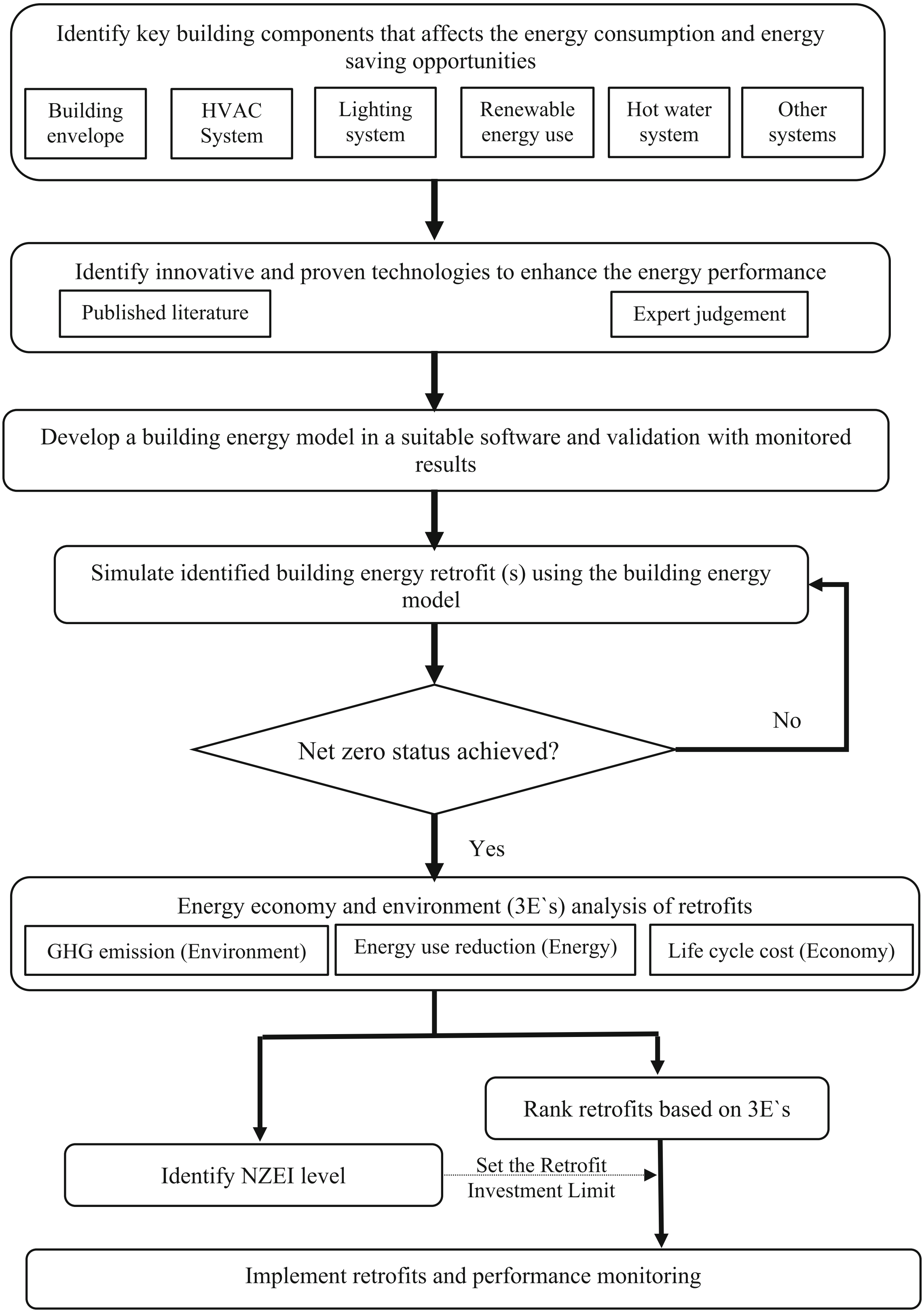

Fig. 2 Energy retrofit planning approach

Table 1 Building parameters and operational data

Building parameter	Details
Total floor area	~9234 m^2
Pool area	~1925 m^2
Length	69.43 m
Building height	12.65 m
Ground floor	4.115 m
Monitored energy use	
Electricity	8196 GJ
Natural gas	6017 GJ
Building envelope	Wooden
Hours of operation	9 am–8 pm
Temperature	24 C
Number of air changes	6 per hour

$$\begin{aligned}&\text{Annual operational energy cost reduction}\\&\quad=\text{Annual initaial energy operational cost}\\&\qquad-\sum_{i=1}^{n}(\text{Energy reduction from retrofit}_i\\&\qquad\times\text{Provincial energy rate})\end{aligned}\tag{1}$$

$$\begin{aligned}&\text{Annual GHG emission from the facility}\\&=\sum_{i=1}^{n}\big(\text{Energy consumption reduction from retrofit}_i\\&\quad\times\text{Emission factor for the region}\big)\end{aligned}\tag{2}$$

$$\begin{aligned}\text{Annualized LCC}_{\text{ES}}=&\ \text{Equivalent annualized}\\&\ \text{cost of initial cost}\\&+\text{Annual Operational cost}\\&+\text{Annualized maintenace cost}\end{aligned}\tag{3}$$

Equivalent annualized cost (EAC) of the initial investment is calculated using Eq. (4) (Sasmita 2010).

$$\text{EAC}=\text{initial investment}\left(\frac{i(1+i)^n}{(1+i)^n-1}\right)\tag{4}$$

Where i is the discounting factor and n is the number of periods.

Regional analysis for Canada

The same building was simulated at different geographical locations in Canada. Details about the locations of the building, electricity grid, and tariff information are presented in "Appendix". In order to identify the optimal retrofit investment curves for energy cost reduction, energy

Fig. 3 Schematic of design builder energy model

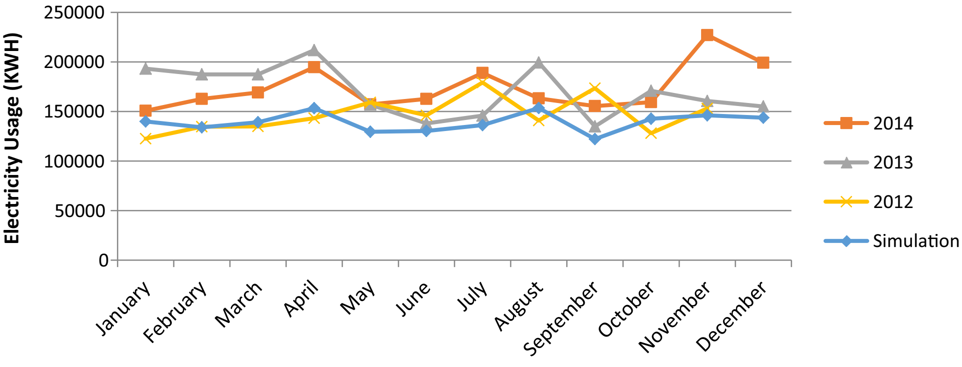

Fig. 4 Model validation

Table 2 Proven retrofits for aquatic centres

Building envelope		
R1	Increase the insulation of the roof	(CEI Architecture Planning Interiors 2011)
R2	Replace front glazing with a double-glazed system	(CEI Architecture Planning Interiors 2011; Sydney Water 2011)
R3	Increase the insulation of walls	(CEI Architecture Planning Interiors 2011)
Lighting system		
R4	Change the lighting to LED (except swimming pool areas)	(Stantec Consulting Ltd. 2008; Township of Esquimalt 2013)
R5	PV electricity for the building	(Sydney Water 2011; City of Toronto 2014)
R6	Daylight sensing lighting controls	(City of Toronto 2009)
Pool heating		
R7	Geothermal pool heating system	(International Energy Agency 2011)
Hot water supply		
R8	Use of solar preheater	(Sydney Water 2011)
R9	Solar hot water systems	(Sydney Water 2011; Township of Esquimalt 2013)
Building HVAC system		
R10	Solar ventilation air preheating	(US Department of Energy 2012)

consumption and LCC should be identified. This step required a large number of data points to construct a graph. Hence, various combinations of retrofits identified in Table 1 were considered. Microsoft Excel was used to create the required data points for the analysis. Equations (1–3) were used to calculate all possible data points. For 10 retrofits, 1024 combinations were created. A second-order polynomial function was used for similar applications in the literature (Jafari and Valentin 2015), and it had the best fit for data points. Hence, the second-order polynomial function was assumed for the trend line. Optimal investment for retrofits, retrofit investment for new zero GHG, and energy status were calculated for various regions of Canada assuming the same building. Microsoft Excel solver was used to solve the polynomial function obtained for LCC, GHG emission, and energy cost reduction.

Results

Energy simulation for the considered building returned the following results. Figure 4 compares simulation results with monitored values and shows that the energy model is a reasonable representation of the building in focus.

Table 3 presents values calculated for energy cost reduction, lifecycle cost, and GHG emissions for the Okanagan region of BC. Detailed cost and energy information are included in "Appendix". Retrofits are ranked based on energy reduction, GHG emission, and lifecycle cost, assuming equal weight for the three parameters. Based on the analysis, automatic lighting controls ($R6$) are the optimal retrofit.

Based on Fig. 5, net zero emission investment (NZEI) is CAD 824,640 for the building in focus. These retrofits will achieve an annual operational cost reduction of CAD 57,737.

Therefore, in order to become NZEB, the optimal approach is installing retrofits $R1$, $R2$, $R3$, $R5$, $R6$, $R7$, $R8$, $R9$, and $R10$ (Cost CAD 856,796).

Regional analysis

The impact of optimal retrofit alternatives on regional characteristics is presented in Table 4. Table 4 depicts that optimal retrofits differ based on the provincial grid and energy tariff.

Table 5 lists net zero energy installation (NZEI) for different provinces of Canada. Per floor area, NZEI was calculated to generalize the findings. This data would assist in capital budget planning for building energy retrofits. The analysis was not conducted for Prince Edward Island, Newfoundland and Labrador, the Yukon, and the Northwest Territories due to unavailability of data. Results show that geographical variation is a main factor affecting optimal retrofit.

Figure 6 presents NZEI as a function of the provincial grid emission factor. There is a strong correlation ($R^2 = 0.9715$) between the grid emission factor and NZEI.

Discussion

Renovation and refurbishment of buildings is a more prudent approach than new building construction. Building renovation and refurbishment provides improved functional quality, durability, and economy compared to

Table 3 Energy cost reduction, GHG emission reduction, and LCC for various retrofit investments (for Okanagan, BC)

Retrofit#	Energy demand reduction (GJ)	GHG emission (kg CO2 eq)	Annualized LCC (CAD)	Rank
*R*1	735	36,675	2085	10
*R*2	768	38,342	1233	9
*R*3	1270	63,348	−131	3
*R*4	737	530	−425	4
*R*5	461	332	−343	6
*R*6	388	279	−1453	1
*R*7	2451	122,250	1255	2
*R*8	178	8891	−22	8
*R*9	350	17,455	−43	7
*R*10	669	33,341	−65	5

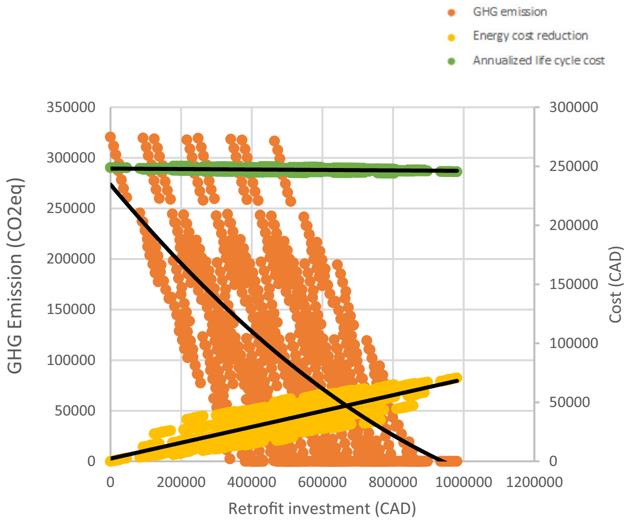

Fig. 5 Retrofit investment analysis for BC

demolition and reconstruction (Poel et al. 2007). Also, the use of proper refurbishment methods contribute to environmentally sound buildings with social and financial value throughout the life cycle of a building (Poel et al. 2007). A planned and systematic investment planning approach was proposed for achieving NZEB. An energy simulation analysis was conducted to identify the optimal energy retrofit investment and investment to achieve net zero emission status. This study was extended to various provinces in Canada to identify the impact of regional grid and energy (i.e. electricity and natural gas) tariffs on retrofit investment planning.

Based on the analysis, economic and environmental viability of the retrofit would change as a result of locational parameters (e.g. energy tariff, grid emission factor). Hence, proven technology in one province would not be feasible in a different province. Detailed analysis is needed

Table 4 Optimized retrofit for different provinces

Energy carbon LCC-based rank								
Retrofit	Nova Scotia	New Brunswick	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
*R*1	8	9	8	9	5	10	10	10
*R*2	4	6	7	7	3	7	9	9
*R*3	2	2	1	5	2	2	4	3
*R*4	3	3	10	1	10	3	2	4
*R*5	7	7	9	4	9	5	3	6
*R*6	6	4	6	3	8	4	1	1
*R*7	1	1	2	2	1	1	7	2
*R*8	10	10	5	10	7	9	8	8
*R*9	9	8	4	8	6	8	6	7
*R*10	5	5	3	6	4	6	5	5

Table 5 NZEI for recreational centre buildings

Province		Nova Scotia	New Brunswick	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
Net zero emission investment (NZEI)	Total	2,902,757	1,887,861	762,719	1,295,502	639,711	1,887,861	2,689,253	924,460
	CAD/ m^2	314	204	83	140	69	204	291	100

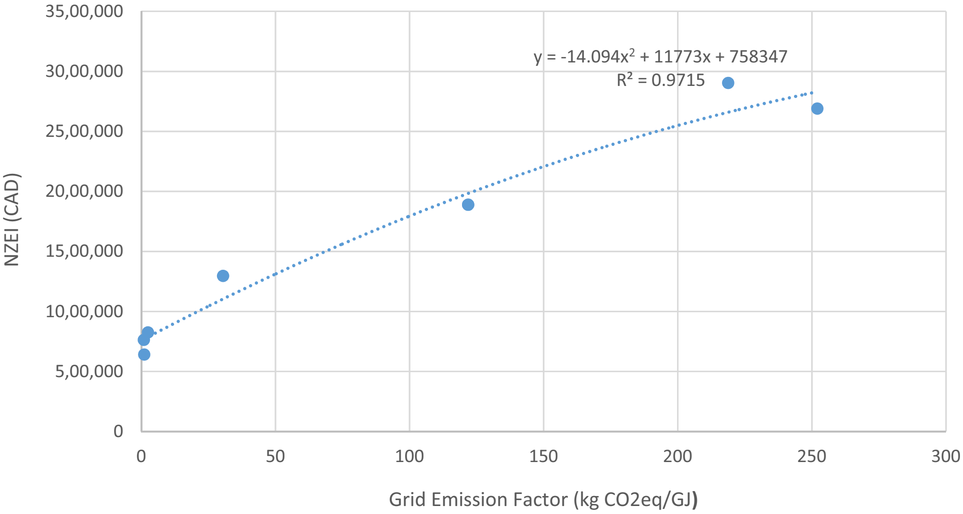

Fig. 6 NZEI versus grid emission factor

before retrofitting the built environment. This study further investigated the correlation between the grid emission factor and NZEI. The strong correlation reveals that larger investments are needed to achieve net zero emission in provinces such as Alberta and Nova Scotia. Per floor area, investment cost identified in this study can be used directly in energy investment planning for aquatic centre buildings with similar configurations.

The analysis for the operating building in BC revealed that the NZEI is CAD 856,796 and annual operational cost reduction is CAD 57737. Based on the analysis, the simple payback period is 14.8 (~15) years. This is a significant time span and can be associated with significant uncertainty due to macroeconomic factors. Hence, it is important to incorporate various uncertainties in retrofit LCC calculation using a suitable method (Ruparathna et al. 2017). In 2016, a tonne of GHG was valued at CAD 41 and is expected to increase in the future (Environment and Climate Change Canada 2016). If the monetary value of all NZEB benefits is considered, the payback period would be further shortened.

Several studies in the past have revealed that, except at the end of the life stage, retrofitted buildings outpace new buildings in assembly and operation phases (McGrath et al. 2013). Building retrofits are commonly analysed based on their impact on energy and lifecycle cost, overlooking lifecycle impacts (Jafari and Valentin 2015). Various factors can affect the decision-making related to refurbishments, such as economy, impact on the ecological environment, and heritage value (Kovacic et al. 2015). The lifecycle impact differs depending on the geographic location. Hence, incorporating lifecycle impacts of retrofits can contribute to a holistic analysis of a retrofit. These decisions should be supported by adequate information, incentives, knowledge, and access to capital (Hinnells 2008). Currently, the construction industry lacks such decision support frameworks.

The purpose of this study was to identify the trend line of GHG emissions, lifecycle cost, and energy cost. One thousand and twenty-three combination scenarios were analysed using ten different retrofits to determine the trend lines. The analysed list of retrofits were commonly used in aquatic centres. There are other popular retrofits, such as heat recovery, which could have been considered in the analysis. Incorporating additional retrofits will further improve the accuracy of the trend lines. In the context of the building considered, net zero emission does not achieve net zero energy or net zero cost status; the primary reason is the zero emission hydroelectricity used in the building. Even though the emission factor of the BC electricity grid is 9.1 g $CO_{2(eq)}$/kWh, energy utility companies supply electricity with low emission factors. Therefore, net zero cost status is not achieved during the zero emission stage. Energy operational cost reduction at NZEI in provinces with a high grid emission factor (e.g. Alberta) would be greater than in provinces with low grid emission factor (e.g. BC). Similar to the above, low emission electricity can be purchased from utility companies at different tariffs, lowering the net zero emission retrofit investment.

Buildings classified as net zero energy or net zero emissions can be connected to the grid (Steven Winter Associates Inc 2014). This energy would be utilized at times when renewable energy cannot meet the building's energy demand. Where the law permits, the surplus on-site generation can be supplied to the grid. Due to high costs associated with energy storage, grid connection ensures reliability of the building energy system. Energy exported from the building to the grid can positively impact the project economics.

The proposed approach can be applied in budgeting for energy retrofits for buildings. Presently, retrofits are planned on an ad-hoc basis. The proposed systematic procedure will ensure value for money in case of limited financial resources. This study highlighted the regional variability of energy retrofit impacts due to climatic, tariff, and grid differences. This highlights the importance of focusing on detailed analysis of a retrofit project incorporating priorities of institutions. The proposed method allows the organization to set weights for the 3Es (i.e. energy, economy, and environment) to identify the best retrofit alternative, which may not be the most economically sound alternative. Additionally, as public buildings are operated using public money it is important to maintain transparency in management decisions. Public institutions are compelled to reduce GHG emission from buildings with the recent carbon neutral corporate climate action plans. Hence, this study provides a structured approach that enables them to proceed to this goal without affecting the transparency of the process.

Implementing NZEI is a challenge due to budget restrictions in public entities. These retrofits should be implemented as annual packages to match the annual budget allocation. Hence, a systematic sequential procedure should be adopted to achieve the eventual zero emission status. Despite huge interest in NZEB within the industry, limited frameworks are available to guide users in achieving zero emission status.

Limitations of this study

Several limitations were observed in this study, and adjustments were made to mitigate their impact. Further research on these limitations would strengthen the movement towards NZEB.

- Findings from this study (NZEI for buildings) could be generalized only after extensive studies. The above results could be used for buildings with similar configurations, even though NZEI could differ with building use, size, etc.
- LCC cost parameters are associated with significant uncertainties. Electricity and natural gas rates in major cities across Canadian Provinces were identified from the literature. These rates may change by utility provider and are subject to inflation over time. There may also be rate arrangements between building owners and utility providers. This drawback was minimized by adopting novel energy retrofit lifecycle costing methods.
- This analysis ignored deterioration of equipment and building components, and replacing retrofits at the end of their economic life. Deterioration of equipment will reduce the components' performance, eventually affecting the results. However, future technologies will be more energy efficient and more economical than those currently in use. This would be a main uncertainty associated with this analysis.
- The GHG emission factor of natural gas was assumed to be equal for all provinces due to data limitations. This value can vary from province to province due to differences in extraction, processing, and transportation. Currently, landfill gas is used as renewable natural gas with a low GHG emission factor. Since the supply of renewable natural gas is limited, it was omitted from this analysis.
- This study assumed polynomial functions to GHG emission, energy cost reduction, and lifecycle cost. This assumption is another uncertainty associated with the results. However, the results display minor deviations when different trend lines were assumed.
- This study ignored the time dependency of grid source energy. Time-dependent valuations for time of use source energy is an important factor in determining the net zero emission. Hence, real-time building management is needed to maintain the net zero emission status.
- The purpose of this study was to identify the trend line of the GHG emission, lifecycle cost and energy cost. One thousand and twenty-three combinations scenarios were analysed using ten different retrofits to determine the trend lines. The analysed list of retrofits was commonly used in aquatic centres. There are other popular retrofits such as heat recovery which could have considered in the analysis. Incorporating additional retrofits will further improve the accuracy of the trend lines.
- The proposed approach ignores interactions between energy retrofits. For example, LED lighting has a lower heat output than fluorescent lighting, which can have an impact on the heating energy demand. Interactions can be accounted for when simulating each retrofit scenario.

However, simulating a large number of energy scenarios will be time consuming.

Conclusions

Increased awareness of climate change mitigation has stimulated an interest in building energy retrofitting. The optimal retrofit for buildings depends on factors such as climate, tariffs, local grid, initial investment, and institutional goals. Detailed analysis of the retrofit is essential in the prefeasibility stage. In order to ensure transparency and effectiveness, retrofit planning should be standardized. Due to the service life of the building, it is important to incorporate the associated uncertainties. The results of this research revealed that NZEI is strongly correlated to the grid emission factor. Hence, the proposed approach would contribute to existing practices by achieving maximum emission reductions as well as being financially viable.

The findings of this study could be extended to several other areas. First, the proposed methodology could be developed for different types of commercial and institutional buildings. A similar study would help to establish a stronger correlation between NZEI and grid emission factor. The aforementioned findings could be used to develop a generalized tool that would be used in energy retrofit planning. Second, it is important to study the uncertainty associated with the parameters. Third, enabling the ability to integrate user preference into the retrofit planning will enhance the flexibility of the proposed concept. This flexibility can be achieved by defining a weight scheme for the parameters. The aforementioned improvements would lead to a user-friendly and industry-ready decision-making tool for building retrofit planning. Finally, further research is needed on implementing the findings from this research. Characteristics of retrofits vary from one to another (e.g. service life). Hence, a systematic capital expenditure planning approach should be developed to plan retrofit installation to gain the best value for the building owners.

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Appendix

See Tables 6 and 7.

Table 6 Energy simulation results

Component	Description	Investment	Energy saving (GJ)	
			Natural gas	Electricity
Building envelope				
R1	Increase the insulation of the roof	119,585	735	0
R2	Replace front glazing with a double-glazed system	89,380	768	0
R3	Increase the insulation of walls to R38	83,248	1270	0
Lighting system				
R4	Lighting retrofit to LED	124,000	0	737
R5	PV electricity for the building	248,300	0	462
R6	Daylight sensing lighting controls	92,283	0	388
Pool heating				
R7	Geothermal pool water heating	178,000	2451	0
Hot water supply				
R8	Use of solar preheater	9,000	178	0
R9	Solar hot water systems	15,000	350	0
Building HVAC system				
R10	Solar ventilation preheating	22,000	669	0

Table 7 Provincial grid and natural gas data

Province	Energy rate (CAD/GJ) (Manitoba Hydro 2015)	Emission factor (kg CO2 eq/GJ)	Energy rate (CAD/GJ)	Emission factor (kg CO2 eq/GJ) (Ministry of Environment BC 2016)
Newfoundland and Labrador	N/A			
Prince Edward Island	N/A			
Nova Scotia (Environment Canada 2014; Heritage Gas 2016)	4.27	219	11.65	49.87
New Brunswick (Environment Canada 2014; Enridge Gas New Brunswick 2016)	3.52	122	6.08	
Quebec (Environment Canada 2014; Gaz Métro 2016)	2.75	1	2.37	
Ontario (Environment Canada 2014; Union Gas 2016)	4.20	31	4.73	
Manitoba (Environment Canada 2014; Manitoba Hydro 2016)	2.26	1	9.34	
Saskatchewan (Environment Canada 2014; SaskEnergy 2016)	3.43	122	4.30	
Alberta (Environment Canada 2014; ATCO Gas 2016)	3.15	253	1.91	
British Columbia (Environment Canada 2014; FortisBC 2016)	3.17	3	2.31	
Yukon	N/A			
Territories and Nunavut	N/A			

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